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GUIDELINES ON REDUCING CARBON FOOTPRINT OF ROAD PROJECTS

INDIAN ROADS CONGRESS
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GUIDELINES ON REDUCING CARBON FOOTPRINTS OF ROAD PROJECTS

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Guidelines on Reducing Carbon Footprints of Road Projects

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ABBREVIATIONS/ NOTATIONS

AADT	Annual Average Daily Traffic
ADB	Asian Development Bank
AGTB	Above Ground Tree Biomass
ARAI	Automotive Research Association of India
BD	Bulk Density
BGTB	Below Ground Tree Biomass
BEF	Biomass Expansion Factor
CAB	Carbon Stock in above Ground Biomass
CBR	Californian Bearing Ratio
C&D	Construction and Demolition
CH_4	Methane
CO_2	Carbon Dioxide
CS	Country Specific
CNG	Compressed Natural Gas
CEA	Central Electricity Authority
CF	Correction Factor
CTB	Cement Treated base
CSB	Cement Stabilised base
CRRI	Central Road Research Institute
CPCB	Central Pollution Control Board
dm	Dry matter
FAO	Food and Agricultural Organization of United Nations
F-gases	Fluorinated Gases
GHG	Greenhouse Gas
GOI	Government of India
HMA	Hot Mix Asphalt
H_2O	Water
HAC	High Activity Clay
HCV	High Carriage Vehicle
IANR	Institute of Agriculture and Natural Resources
IPCC	Intergovernmental Panel on Climate Change
IRC	Indian Roads Congress
ICE	Inventory of Carbon & Energy
ICAP	Indian Clean Air Program
LAC	Low Activity Clay
LCV	Light Commercial Vehicle
MoEFCC	Ministry of Environment, Forest & Climate Change
MoRTH	Ministry of Road Transport and Highways
N_2O	Nitrous Oxide
NCSEC	National Computational Science Education Consortium
O_3	Ozone
OC	Organic Carbon
PCC	Portland Cement Concrete
PMGSY	Pradhan Mantri Gram Sadak Yojana
SOC	Soil Organic Carbon
RCC	Rolled Compacted Concrete
RAP	Reclaimed Asphalt Pavement
tCO_2e	Carbon Dioxide Equivalent in Ton
TERI	The Energy Resource Institute
USDA	United States Department of Agriculture
WRB	World Reference Base
WMA	Warm Mix Asphalt

UNITS OF MEASURE

Area	Ha	Hectare
	Sqm	Square Meter
Weight	kg	Kilogram
	gm	Gram
	Mg	Megagram (or 10^6 Gram)
Volume	m^3	Cubic Meter
Length	Km	Kilometer
	mm	Millimetre

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(as on 19th November, 2020)

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PREFACE

These guidelines have been formulated by IRC partially fulfilling the mandate of Committee on Reduction of Carbon Footprint in Road Construction and Environment (G-3), subsequent to IRC:SP:122 on 'Guidelines for Green Rating of Highways' to provide a standard methodology for evaluating the criteria on carbon footprint and a summary of GHG efficient technologies.

These guidelines consists of Part –I as 'Introduction', Part-II as 'GHG Estimation Methodology and GHG Efficient Technologies for Road Construction and Maintenance' followed by Part- III as 'GHG Estimation Methodology for Vehicular Emission during Operations Stage of Roads' and Part-IV and Part-V as Case Study and Conclusion respectively.

It is pertinent to mention that emission factors suggested in these guidelines are the default emission factors available at open sources. These can be used unless the Governmment of India (GOI) comes up with India specific emission factors for all road construction activities and materials.

It is also pertinent to mention that Part-III does not include the carbon efficient vehicular and fuel technologies as extensive work is already being done by concerned bodies viz. Fuel consumption standards by Ministry of Power for Motor Vehicles, Motor Vehicles Act by Ministry of Law and Justice, Bharat Stage Norms for fuel by Ministry Petroleum & Natural Gase etc. Also that the road design consultant, contractors and concessionaires have no control on the fuel and Vehicular Technologies.

The initial draft of these guidelines have been prepared by Ms. Tamosi Bhattacharya, Environment Planner and Dr. Siksha Swaroopa Kar, Principal Scientist, CRRI after studying various available national and International practices and data for road projects and finalized after a rigorous and critical review by the honourable members of Committee on Reduction of Carbon Footprint in Road Construction and Environment (G-3). Gaps, if any, in the guidelines will be duly filled in due course of time based on experience and further enrichment of literature.

During the 11th meeting of the G-3 Committee held on 11th July, 2020, the draft of the Guidelines was approved for submission to the GSS Committee.

The List of G-3 Committee personnel is given below:

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(Nirmal, S.K.)

The General Specifications & Standards Committee (GSS) considered and approved the draft guidelines in its meeting held on 19th November, 2020 for placing it before Executive Committee and IRC Council. The Executive Committee in its meeting held on 18th February, 2021 considered and approved the same for placing it before the Council.

The IRC council in its 221st Council Meeting held at New Delhi on 20th February, 2021 considered and approved the "Guidelines on Reducing Carbon Footprints of Roads Projects" for printing.

The Indian Roads Congress would therefore, welcome suggestions and feedback from users so that any further modification/updating may be incorporated in due course.

PART - I
INTRODUCTION

1. General

The concept of 'Green' has a wider scope than it literally means and encompasses the mechanism of conserving, enhancing and managing the quality and quantity of natural resources. One of the indicators of 'green' is the amount of reduction possible in greenhouse gas (GHG) emission.

There is an urgent need to avoid ecological degradation which is currently getting triggered by GHG emission. GHG has increased from 278 ppm in pre-industrial era to 414.7ppm in May, 2019. This is the highest level in human history recorded at Mauna Loa Observatory (ESRL,2019).This rise in CO_2 shows a remarkably constant relationship with fossil-fuel burning, and can be well accounted for based on the simple premise that about 60 percent of fossil-fuel emissions stay in the air (NASA,2019). With this rate, temperature is likely to increase by 4°C by 2100 leading to around 1m rise in sea level. Maintaining the increase in global temperature below 2°C would prevent many of the worst impacts of climate change from occurring. Doing so requires urgent action to reduce carbon emissions and increase carbon sinks. Delaying action would significantly increase the cost of keeping warming below 2°C. According to Intergovernmental Panel on Climate Change (IPCC) scenarios, delaying action until 2030 would increase total mitigation costs by 50 percent (IPCC, 2014). Overall economic growth is also predicted to reduce by 1.3 % with every 1°C rise in regional temperature (World Bank, 2012).

Anthropogenic emission of GHG is acting as a slow poison for the natural ecosystem and globally transportation is its third largest emitter (IEA,2018). India is the 4th largest GHG emitter in the world with a share of 7%. In India, total GHG emission is 2,306,295.43 Gigagram CO_2 eq. (with Land Use, Land use Change and Forestry) out of which energy sectors has a share of 73% and transportation contributes to 13 % of the emissions by energy sector (MoEFCC, 2018). Out of all modes, road transportation alone has a share of approximately 90% (IEA,2018).

Use of energy efficient locally available materials, additives, new technologies along with adoption of efficient road designing can reduce the GHG emitted from roads both during construction and operation period. It is pertinent to mention that timely and quality maintenance in the operations stage also has a role in reducing the carbon footprint due to lesser wear and tear of vehicle engines. It is interesting to note that the distress growth rate of pavement increases with time when the pavement is not maintained timely. If timely maintenance is carried out, the pavement life will increase two fold compared to the unmaintained pavement, hence, the carbon emission is also reduced by reducing resurfacing of pavement.

To determine whether a particular construction methodology or a design is emission efficient, it is required to estimate GHG emission on project to project basis.

2. Objective

These guidelines intend to facilitate with the procedure of GHG emission and sequestration calculation for road projects. These guidelines also highlight the GHG emission efficient technologies for road projects.

3. Scope

This document provides the methodology for estimation of GHG emission from construction, maintenance and operation stage of road project. A broad range of emission efficient materials & technologies have been listed out in this document for the construction and maintenance stage of road project. A representative case study has been included solely for the purpose of explaining the GHG calculation methodology.

4. Methodological Approaches as per IPCC for GHG Emission Estimation

IPCC has classified the methodological approaches for GHG estimation in three different Tiers, according to the quantity of information required, and the degree of analytical complexity (IPCC, 2003, 2006).

TIER 1

The Tier 1 method is fuel-based, since emissions from all sources of combustion can be estimated on the basis of the quantities of fuel combusted (usually from national energy statistics) and average emission factors. Tier 1 emission factors are available for all relevant direct greenhouse gases.

The quality of these emission factors differs between gases. For CO_2, emission factors mainly depend upon the carbon content of the fuel. Combustion conditions (combustion efficiency, carbon retained in slag and ashes etc.) are relatively unimportant. Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of fuels combusted and the averaged carbon content of the fuels (IPCC, 2006).

TIER 2

In the Tier 2 method for energy, emissions from combustion are estimated from similar fuel statistics, as used in the Tier 1 method, but country-specific emission factors are used in place of the Tier 1 defaults. Since available country-specific emission factors might differ for different specific fuels, combustion technologies or even individual plants, activity data could be further disaggregated to properly reflect such disaggregated sources. If these country-specific emission factors indeed are derived from detailed data on carbon contents in different batches of fuels used or from more detailed information on the combustion technologies applied in the country, the uncertainties of the estimate should decrease, and the trends over time can be better estimated.

TIER 3

In the Tier 3 method for energy, either detailed emission models or measurements and data at individual plant level are used where appropriate. Properly applied, these models and measurements should provide better estimates primarily for non-CO_2 greenhouse gases, though at the cost of more detailed information and effort.

Type of Emission factors used, by MoEFCC to prepare a GHG inventory for UNFCCC, are both Default (D) and Country Specific (CS) for CO_2 and Level of Methodological Tier Employed for CO_2 emission estimation is T1, and T2. In case of N_2O and CH_4, it is D and T1 (MoEFCC, 2018). It is advisable to use default emission factors and T1 level of methodological Tier unless CS emission factors are available and in such case Tier 2 level of methodology shall be used.

TERMINOLOGIES

Carbon Footprint	It is the amount of greenhouse gases, primarily carbon dioxide, methane and nitrous oxide, released into the atmosphere by a particular human activity.
Carbon Dioxide (CO_2)	CO_2 is a naturally occurring gas, and a by-product of burning fossil fuels or biomass, of land-use changes and of industrial processes. It is the principal anthropogenic greenhouse gas that affects Earth's radiative balance. It accounts for around 20% of the greenhouse effect. It is the reference gas against which other greenhouse gases are measured and therefore it has a Global Warming Potential of 1.
CO_2-equivalent emission	The amount of CO_2 emission that would cause the same radiative forcing as an emitted amount of a well-mixed greenhouse gas, or a mixture of well mixed greenhouse gases, all multiplied with their respective Global Warming Potentials to take into account the differing times they remain in the atmosphere.
Direct Emissions	Or "point of emission" are defined as the point in the energy chain where they are released and are attributed to that point in the energy chain, whether a sector, a technology or an activity. e.g. emissions from coal-fired power plants are considered direct emissions from the energy supply sector.
Emission Factor	Emission factor is the rate of emission per unit of activity, output or input.
Embodied Carbon Emissions	CO_2 emissions are released during the production of goods and materials. The production process includes extraction or mining of raw materials, transportation, processing and distribution of finished goods to the consumer. CO_2 emission released due to all these activities account for the embodied emission of a material/goods/ machinery. In other words, it's the life cycle CO_2 emission of a particular material, goods or machine.
Greenhouse gases	Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Methane (CH_4) and Ozone (O_3) are the primary greenhouse gases in the earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere,

such as the halocarbons and other chlorine and bromine-containing substances, dealt with under the Montreal Protocol. Besides Carbon Dioxide, Nitrous Oxide and Methane, the Kyoto Protocol deals with the greenhouse gases of Sulphur Hexafluoride, Hydro-Fluorocarbons, and Perfluorocarbons (IPCC, 2007).

Sequestration Sequestration is carbon storage in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO_2 from the atmosphere through land-use change, afforestation, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture.

PART - II

GHG ESTIMATION METHODOLOGY AND GHG EFFICIENT TECHNOLOGIES FOR ROAD CONSTRUCTION AND MAINTENANCE

1. Emission causing Activities of Road Projects

There are several activities performed during construction (including pre- construction activities), maintenance and Operation period that either emits GHG or removes its sink.

Construction

a) Use of Construction Materials (Type and Quantity)

b) Lead of Sources of Materials and Vehicle Loading

c) Removal of Trees or Green Cover (Loss of Emission Sink)

d) Amount of Excavation for Cut and Fill

e) Lead for Cut (Disposal Site) and Fill (Source) Materials and Vehicle Loading

f) Fuel/Electricity used in Labour/Construction Camps and Vehicles used by Contractors/ Supervisors

g) Use of Construction Machineries

Maintenance

a) Material Quantity and Type

b) Fuel used by Machineries

c) Lead of Materials Sources and Vehicle Loading

d) Street lighting- Usage of Electricity

e) Other Components of Construction Period may be applicable as per Actual Condition

2. GHG Estimation Methodology for Construction Period

During construction, the main activities or components taken into consideration are:

- Embodied and direct emission of construction materials
- Direct and embodied emissions due to combustion of fossil fuel like diesel, petrol, CNG used in different types of machineries at the project construction site.
- Emission due to use of timber/coal/LPG/electricity etc. for cooking, lighting, cooling at construction site shall also be considered.
- Embodied GHG emission of vehicles and machineries are not accounted for as the same machineries and vehicles are likely to be used for multiple road construction projects and this would lead to multiple counting.
- Loss of potential carbon sink in the form of removal of vegetation or paving of soil area
- In direct emission due to burning of the removed timber being used as fuel by an end user (be it industrial or domestic) outside the project site for a purpose not related to the project.

Calculation of emission can be done by first identifying the activity and its intensity and then multiplying it with its emission factor (Formula -1). For example, to compute GHG emission from asphalt paver being used during construction, one may note the total fuel consumed in a certain period and multiply it with the emission factor of the fuel or say to compute it for quarried aggregates, the quantity of quarried aggregates is to be multiplied with its embodied emission factor **(Fig. 2.1)**.

$$E_{(e+d)} = \sum(S_i * E_f) \quad \text{.....(1)}$$

Where,

E= Emissions

(e+d)= (Embodied + Direct)

E_f = Emission Factor

S_i = Source $(A*I)_i$

A= activity and I= intensity

3. GHG Estimation Methodology for Maintenance Period

During maintenance the main activities or components taken into consideration are:

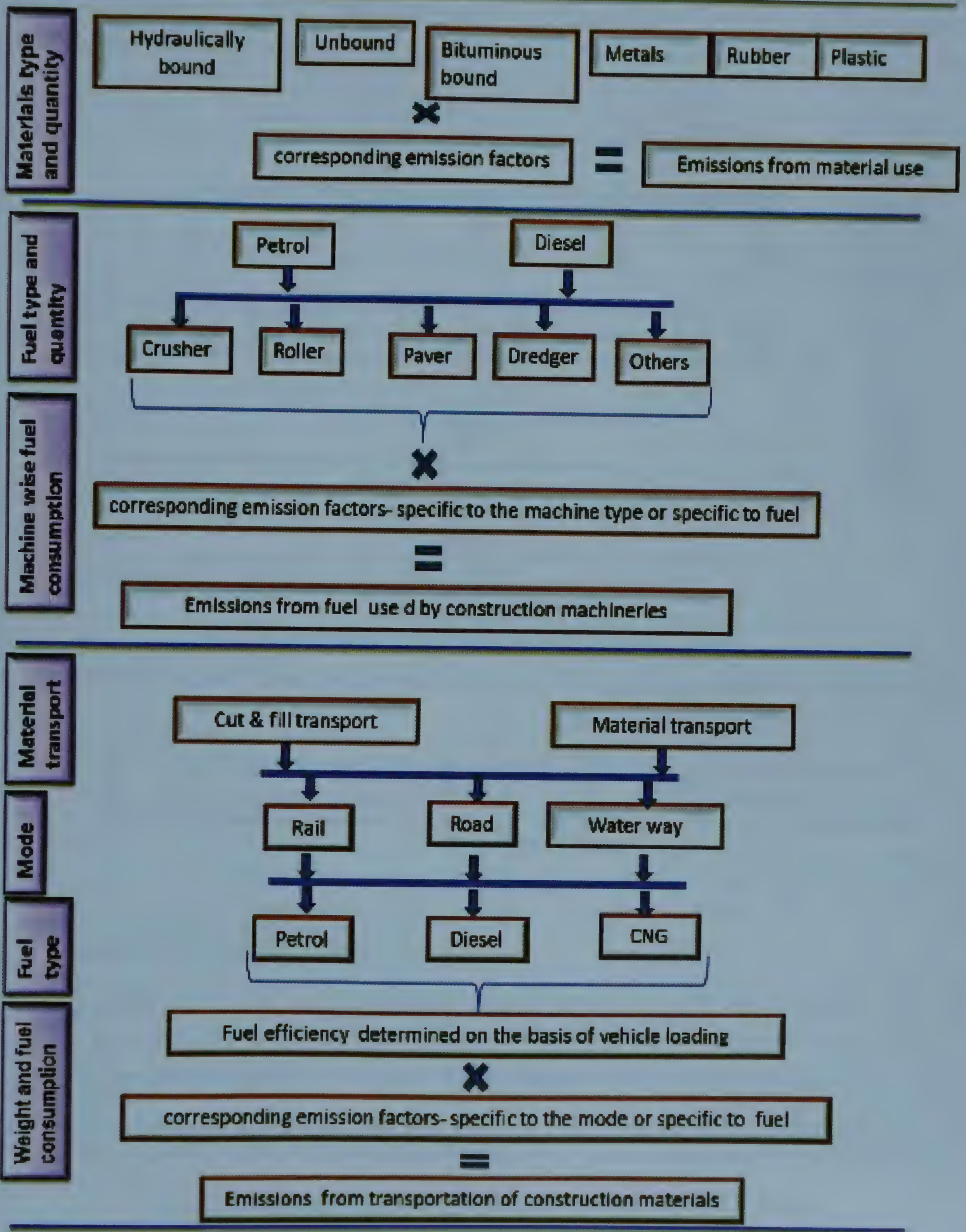
- Embodied GHG emission of construction materials
- Direct and embodied emissions due to combustion of fossil fuel like diesel, petrol, CNG Used in different types of machineries at the project construction site. Emission due to use of timber/coal/LPG/electricity etc. for cooking/lighting/cooling at construction site shall also be considered.
- Embodied emission of electricity used for street/toll plaza/way side amenities lighting/ cooling

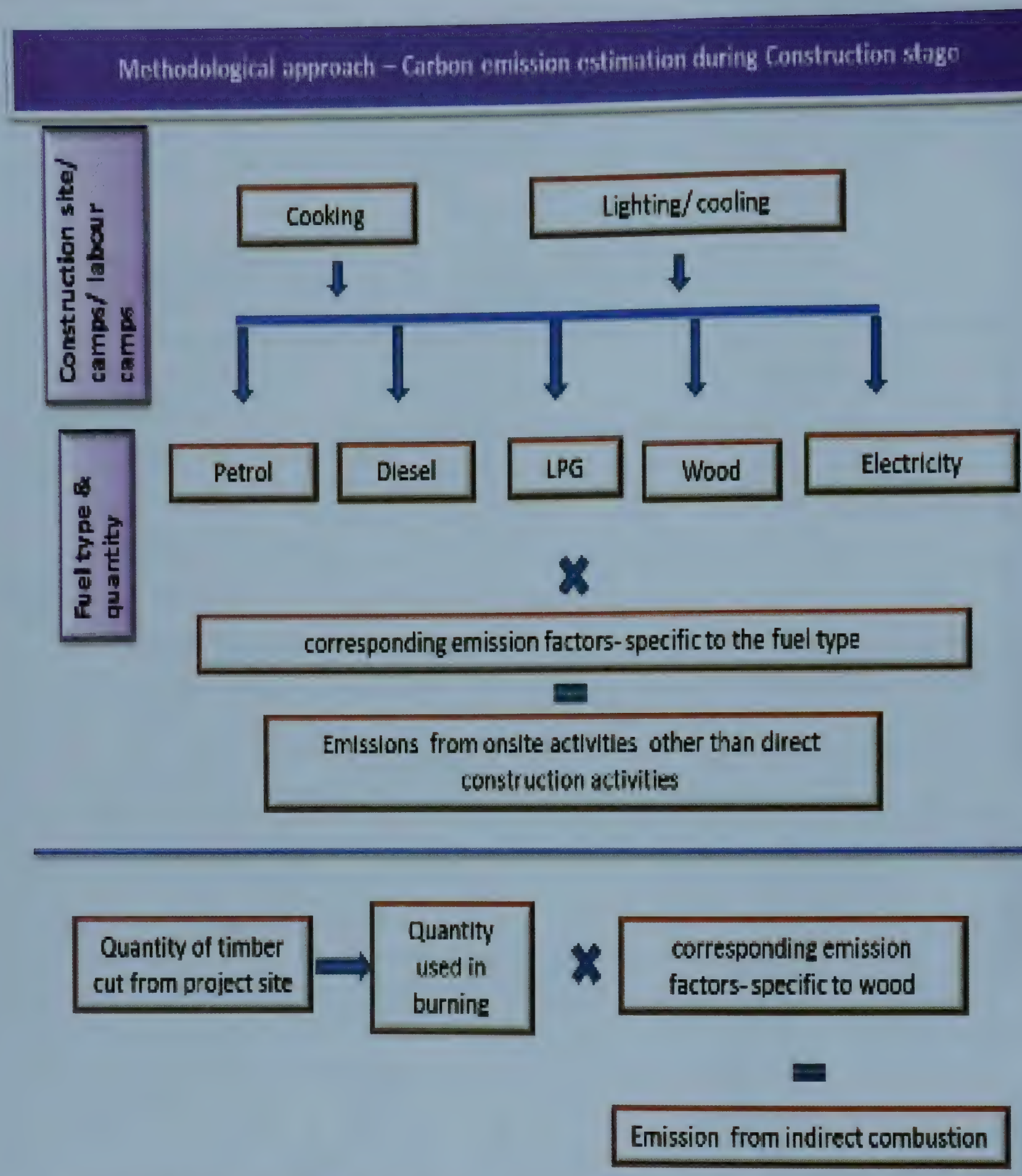
Calculation methodology will be the same as followed for construction phase but will be in a much lower scale. It may also be noted that drains need to be maintained clear of any waste, vegetation etc, that can lead to generation of methane due to decomposition. While calculating total emission of maintenance period, carbon sequestered by road side trees may be deducted from it, to get the net emission.

4. Emission Factors

Direct and embodied emission factors are subject to changes over time with changes in technologies, fuel quality, engine capacity of vehicles and machines etc.Variation in embodied emissions also needs to be understood as it largely depends on the defining boundaries for each material or process or activity. Few emission factors available at open sources are mentioned below that can be used until India has its own emission factors for all road construction materials and activities.

Methodological approach – GHG emission estimation during Construction stage




Methodological approach – Carbon emission estimation during Construction stage
Construction site/ camps/ labour camps
Cooking
Lighting/ cooling
Fuel type & quantity
Petrol
Diesel
LPG
Wood
Electricity
corresponding emission factors- specific to the fuel type
Emissions from onsite activities other than direct construction activities
Quantity of timber cut from project site
Quantity used in burning
corresponding emission factors- specific to wood
Emission from indirect combustion
*As it would be very difficult to get an account of the specific end uses of the timber, a standard emission factor shall be considered for wood irrespective of the process of burning.

Note: The total emission calculated using this process shall be added to the amount of CO_2 that will no more be sequestered due to the felling of trees. Methodology explained later in these guidelines

Fig. 2.1 GHG Emission Estimation during Construction Stage

4.1 GHG Emission Factors of Materials and Fuels

Default emission factors of materials common to road construction in India, as available from different open sources are given in **Table 2.1.** It may please be noted that in case of direct use of any waste materials or by products, the emission factor shall be taken as zero to avoid double counting however emission due to use of fuel/energy for transportation or any other services may be considered. In case any prior processing/treatment is required, fuel/energy used for the same and its emission shall be considered along with its transportation fuel emission.

Table 2.1 Emission Factors for Materials and Fuels

Sl.no	Materials/ Fuels	tCO_2e/ ton	Sources
1	Bitumen	0.4900	Inventory of Carbon & Energy (ICE), Version 2.0, University of Bath, 2011
2	Quarried Aggregate	0.0052	
3	Cement General	0.7400	
4	Sand	0.0051	
5	Steel General (General)	2.8900	
6	Steel General (Recycled)	0.4700	
7	Stone: General (for Slope Protection, Water Harvesting pits etc)	0.0790	
8	Soil	0.0240	
9	General Plastic	3.3100	
10	CNG	2.9376	GHG Platform of India, 2016
11	Natural Gas Liquids	2.8381	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Cross referred from World Resource Institute, 2017.
12	Biodiesels	1.9119	
13	Natural gas	2.6930	
	Fuel	**tCO_2e/ liter**	**Sources**
14	Motor Gasoline	2.2721	2006 IPCC Guidelines for National Greenhouse Gas Inventories. Cross referred from Worl d Resource Institute, 2017.
15	Other Kerosene	2.5197	
16	Gas/Diesel Oil	2.6769	
17	Liquefied Petroleum Gases	1.6118	

In case emission factor is available only in terms of CO_2 and it is required to be converted into CO_2e, the following formulae based on global share of GHG emission can be used to include N_2O and CH_4.

Global share of GHG emission by gas comprise of 76% CO_2, 16 % CH_4 and 6% N_2O and 2% Fluorinated gases (IPCC, 2014).These gases shall be considered only if emitted by a particular material/activity.In case of change in global share of GHG emission, the formula needs to be updated accordingly.

$tCO_2e = tCO_2 + tCH_4 + tN_2O + F\text{-gases}$

Where, $tCH_4 = t\ CO_2 * (16\% \div 76\%)$

$tN_2O = t\ CO_2 * (6\% \div 76\%)$

$tFgases = t\ CO_2 * (2\% \div 76\%)$

It may be noted that this is a rudimentary form of deriving N_2O and CH_4 emission factors and shall be used only where inevitable and shall be mentioned in the project documents prominently.

4.2 GHG Emission Factor of Fuel by Fuel Type & Machine Type

Emissions from machine can be determined by multiplying emission factors of the fuel (available from IPCC based on calorific value assuming 100% oxidation of fuel) to it fuel efficiency.

4.3 GHG Emission Factors of Electricity

Emission factor for electricity is available grid wise from Central Electricity Authority (CEA) of India and is updated from time to time **(Table 2.2)**

Table 2.2 Weighted Average Specific Emissions for Fossil Fuel-Fired Stations in 2016-17(tCO_2/MWh)

Coal	Diesel	Gas	Lignite	Average
0.98	0.59	0.45	1.38	0.82

(Source: CEA, 2018)

5. Methodology for Calculation of CO_2 Sequestration

5.1 CO_2 Sequestration by Soil

Due to conversion of land use from agriculture, forest and vegetation cover to road, the carbon sink in the form of soil is lost. To account for the loss, one can calculate the stock of Soil organic carbon (SOC) that has been sequestered and will not be available in future due to land use/ land cover change. The value of carbon sequestered by soil area converted needs to be added to the overall value of GHG emission of construction stage. Similarly, the amount of carbon sequestered by soil area of compensatory afforestation can be deducted from the GHG emission of maintenance or operation stage.

There are two alternative methods explained here that can be easily adopted by users.

5.1.1 *IPCC Tier-1 Methodology*

Tier -1 Methodology of IPCC uses default reference SOC values of broad type of Climatic Regions and Soil **(Table 2.3)** that can be multiplied to the area of soil to obtain total SOC.

Table 2.3 Default Reference (under native vegetation) Soil Organic Carbon (C) Stocks (SOCref) (tonnes C ha^{-1} in 0-30 cm depth)

Climate region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetland soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	
Tropical montane	88*	63*	34*	NA	80*	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernouxet al. (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# Indicates where no data were available and default values from 1996 IPCC Guidelines were retained.

* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

[1]Soils with High Activity Clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2]Soils with Low Activity Clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, Acidic Alfisols).

[3]Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

[4]Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5]Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6]Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

(Source: IPCC,2006)

5.1.2 *Calculation of SOC based on Empirical Data*

SOC stock can be calculated using the formula (2). The formulae has been referred from Food and Agricultural Organization of United Nations, 2017 (FAO,2017) and slightly modified to compute SOC in kg/ha when sampling depth is 15 cm and bulk density is 1.3 mega gram/m^3. It is estimated that for a BD of 1.3 mega gram/m^3, the soil of 15 cm slice of one hectare weighs equal to 2.245 x 10^6 Kg. For calculation purposes 2.245 is simply taken as 2.24. In the formulae, two zeros are neutralized when the equation is divided by 100 to account for the percent value.

In case the BD varies, the value can be adjusted by dividing 1.3 by actual value of BD. In case of variation in depth other than 15 cm, the value of 22400 can be simply multiplied with the multiplier of 15 (of the depth). For example, if depth is 30 cm then multiplier of 15 is 2, multiply the value of 22400 with 2. However, it must be noted that both BD and OC shall be analysed based on the sample collected from same depth. For computing correction factor, one needs to analyse the percentage of stone (soil particles more than 2mm) content in soil while carrying out textural analysis of soil.

SOC stock (Kg/ha) = (% OC x 22400 x 1.3/BD x CF) .....(2)

Where,

BD= Soil Bulk Density (mega gram/m^3)

22400 =Factor used for conversion of value into kg/ ha when depth is 15 cm and BD is 1.3 mega gram/m^3

%OC= Percentage of Organic Carbon Concentration

CF- Correction Factor (1-% stones)

5.2 CO_2 Emission Factor of Wood or Sequestration by Trees

Trees are required to be felled for construction of roads and this leads to the loss of carbon sink. To account for the loss one can calculate the amount of carbon sequestered by the trees and add the value to overall GHG emission of construction stage. In case of maintenance period/ operation stage carbon sequestered by trees within project area and those planted as part of compensatory afforestation can be calculated and deducted from overall GHG emission.

t is assumed that the amount of carbon sequestered by a tree will be given out while burning. A general methodology can be followed for calculating carbon sequestration in trees. The methodology includes the following (NCSEC,2002).

- Determine the Total (green) Weight of the tree.
- Determine the Dry Weight of the tree.
- Determine the Weight of Carbon in the tree.
- Determine the Weight of Carbon Dioxide sequestered in the tree
- Deternine the Weight of CO_2 sequestered in the tree per year

5.2.1 *Determine the Above-Ground Tree Biomass (AGTB)*

Based on tree species, equations (3) and (4) can be used to calculate the weight of a trees (Alexander Clark IIIet.al., 1986)-

For trees with D < 11:

$W = 0.25*D^2 * H$..... (3)

For trees with D >= 11:

$W = 0.15* D^2 * H$ ..... (4)

Where,

W = Above-Ground Weight of the tree in pounds

D = Diameter of the Trunk in inches

H = Height of the Tree in feet

Depending on the species, the coefficient (e.g. 0.25) could change, and the variables D^2 and H could be raised to exponents just above or below. However, these two equations could be seen as an "average" of all the species' equations.

5.2.2 *Determine Below-Ground Tree Biomass (BGTB)*

The Below Ground Tree Biomass (BGTB) is calculated by multiplying the AGTB with a default value of 0.27, provided by IPCC (IPCC, 2006). AGTB and BGTB can be added to get the total weight of the tree.

5.2.3 *Determine the dry weight of the tree*

An average tree is 72.5% dry matter and 27.5% moisture (IANR,2005). Therefore, to determine the dry weight of the tree, multiply the weight of the tree by 72.5%.

5.2.4 *Determine the weight of carbon in the tree*

The average carbon content is generally 50% of the tree's total volume (Richard, 1992). Therefore, to determine the weight of carbon in the tree, multiply the dry weight of the tree by 50%.

5.2.5 *Determine the weight of carbon dioxide sequestered in the tree*

CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen.

The atomic weight of Carbon is 12.001115.

The atomic weight of Oxygen is 15.9994.

The weight of CO_2 is C+2*O=43.999915.

The ratio of CO_2 to C is 43.999915/12.001115=3.6663.

Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.6663.

5.3 Alternate Method for Calculation of Carbon Sequestration by Trees- Species Specific

Carbon stock in above ground biomass can also be calculated using the formula (5) given below. However these would need species specific data on merchantable volume, basic wood density, biomass expansion factor etc. Species specific information can be referred from published documents of Forest Research of India or any other recognised institute. After calculating the CAB, with formulae (5) however for AGTB, BGTB, carbon content in BGTB and CO_2 sequestered in tree, one needs to follow the above mentioned methodology. Change in units shall be noted. Since this species wise calculation of CAB is more accurate, it is advisable to follow but in the event of absence of BEF, CF and merchantable volume data for a particular species, one can use the methodology mentioned above for that particular species.

$CAB = V \times D \times BEF \times CF$.....(5)

Where,

CAB = Carbon stock in Above-Ground Biomass of given tree species Units: tC

V = Merchantable Volume of given tree species Units: cubic m

D = Basic Wood Density of given species. Units: tdm /cum

BEF = Biomass Expansion Factor

CF = Carbon Fraction of Dry Matter for given species. Units: t C / t.dm (dm is dry matter)

6. GHG Emission Efficient Technologies and Materials

This Section of the guidelines has compiled few GHG emission efficient technologies and materials that can be used as a ready reference. Resource efficiency including optimization of pavement design, reducing lead distance of material sources, use of local and recycled materials etc. are major factors that can lead to reduction in GHG emission. It is recommended to conduct a comparative assessment study of the alternative technologies and materials in terms of GHG emission prior to decision making. It is also recommended to prioritise the use of carbon efficient technologies materials based on site conditions.

6.1 Design Consideration

Optimization of pavement design is one of the main criteria of design that could lead to reduction in GHG emission in comparison to the conventional type. However, it may be noted that choice of materials will also play significant role in reduction of GHG emission of pavements.

6.1.1 *Composite pavement*

A composite pavement structure is defined as a structure comprising two or more layers that combine different characteristics and that act as one composite material. The two most commonly used materials that compose this composite structure are a flexible layer (e.g., HMA) and a rigid layer (e.g., PCC), Cement-Treated Base (CTB), Cement Stabilized Base (CSB), Rolled-Compacted Concrete (RCC), or Lean Mix Concrete). There is no single definition applicable to composite pavements because an HMA overlay on a CTB can be considered a composite pavement; likewise, a thin PCC overlay on an HMA layer, known as whitetopping, has also been considered a composite pavement.

Composite pavements, when compared to traditional flexible or rigid pavements, have the potential to become a cost effective alternative because they may provide better levels of performance, both structurally and functionally, than the traditional flexible and rigid pavement designs. Therefore, they can be viable options for high volume traffic corridors.

IRC:37 gives specifications for design of flexible pavement which includes the design of composite pavement in detail.

Composite pavement systems offer a number of potential advantages and benefits in terms of sustainability. This includes a number of aspects, from increased use of local and recycled materials (and the associated conservation of resources), reduced transportation and hauling costs (incurred for virgin materials), reduced cement contents, reduced pavement thickness and reduced disposal costs, all of which also provide reductions in important environmental impacts such as emissions and energy usage.

In addition to materials, composite systems also provide additional environmental benefits, such as:

- Extended service life, which also reduces the overall life cycle analysis
- High levels of smoothness, which provides user satisfaction and promotes increased fuel economy.
- Reduced congestion, user delays, and reduced emissions as the result of more rapid periodic surface renewals.

It was reported that composite pavement approach is found to be optimal in terms of energy consumption and environmental emissions impact compared to hot mix and concrete overlaying technique through life cycle assessment technique.(Yu, B. and Lu, Q., 2012)

Optimum pavement design needs to be carried out before adopting composite pavement composition.

6.1.2 *Bitumen stabilized base and sub-base*

Bituminous stabilization of base and sub-base layer is achieved by adding bitumen emulsion or liquid bitumen or foamed (expanded) bitumen. This is also known as Cold recycling techniques

like foamed asphalt are gaining ground as effective alternatives to asphalt base and sub-base standard layers. Use of bitumen stabilized base layer is resulted in

- use of Local and Recycled materials (and the associated conservation of resources),
- reduced transportation and hauling costs (incurred for virgin materials),
- reduced pavement thickness due to higher modulus in base layer, and
- reduced disposal / cut transportation cost.

All of these also provide reductions in important environmental impacts such as emissions and energy usage.

IRC: 37 gives specifications for design of flexible pavement which includes the design of stabilised base layer. Also IRC:120-2015 provides the detail mix design of cold recycling technique using both foam bitumen and emulsion. Proper mix design and also optimum pavement design needs to be carried out for implementation of stabilised base and sub-base layer.

6.1.3 *Soil stabilization (chemical stabilization and mechanical stabilization)*

Use of soil stabilization techniques can help in promoting use of locally available materials and enhancing durability of roads. It can also help in optimising pavement thickness, which results in less consumption of natural aggregates.The methods used for soil stabilization fall into two broad categories namely, Mechanical Stabilization and Chemical Stabilization.

Mechanical Stabilization – In this method, the physical nature of soil particles is altered by inducing vibration or compaction or by incorporating other physical properties such as barriers and nailing, without the addition of agents or other particle binding energy. Mechanical Stabilization is achieved by adding virgin aggregate or recycled materials such as recycled asphalt pavement (RAP) or recycled concrete.

Chemical Stabilization – In this method, the desired effect is achieved through means of chemical reaction between stabilizer or the cementitious material and the soil particles. Cementitious materials used for stabilization are: cement, lime, fly ash, bitumen or combination of these and commercially available stabilizers.

The IRC has published several Codes and Specifications Regarding Soil Stabilization Technology such as IRC:28 and IRC:SP:89. MoRTH has also provided Specifications of Materials regarding Chemical Soil Stabilization. However, its use need to be promoted.

Negative environmental issues are associated with utilizing cement and lime in soil stabilization as their production requires large amounts of energy. Cement and lime manufacture also produces high CO_2 emissions, accounting for 5–7% of global CO_2 emissions (McLellan et al., 2011). Other than cement and lime, the most popular additives for increasing bearing capacity of soil are such as flyash, polymers, enzyme, bitumen emulsions, geopolymers etc.Assessment of GHG emissions shall be conducted before finalizing the Stabilization Techniques.

McLellan et al. (2011) conducted a sustainability comparison study between Soil Stabilization using cement and geo-polymers, which revealed that geo-polymers reduced greenhouse gas emission by 44–64%.

6.1.4 *Use of high modulus binder*

Use of high modulus binder can improve durability, and reduce costs and resource use (Geng, H. et.al, 2011) in roads construction by reducing the pavement thickness by upto 30-40%. Along with material savings, use of high modulus binder will reduce the emission through transportation of material and construction equipment usage.

6.2 Geotechnical Measures

6.2.1 *Use of local and marginal material*

As sources of conventional road construction materials like premium grade stone aggregates, sand, etc deplete in the country, road construction using marginal and waste materials in road works is getting prominence. It is possible to use locally available marginal materials and soft aggregates by suitably modifying them with addition of lime or cement or an additive other than cement/lime and even through mechanical stabilization depending upon their strength characteristics and other chemical properties (including water absorption, etc.). Use of locally available marginal material would help not only in cost reduction but also in protecting the environment, reducing carbon footprint in the process as well as time of construction.

It is encouraged for GIS mapping of marginal materials available in the country, developing suitable stabilizers and methodologies to use such waste and marginal materials, characterization of waste and marginal materials, etc. Locally available or marginal materials may not sometimes meet the requirements of gradation and plasticity. So, before using such material, laboratory evaluation to check the suitability of material for road construction shall be done. Also, environmental impact of using such materials in road works, viz. heavy metal leaching and ground water contamination is also required to be assessed prior to field usage.

6.2.2 *Use of geo-synthetics*

Geo-synthetics are synthetic products, where at least one of the components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three dimensional structure, non-woven, knitted, or woven which is used in contact with soil/rock and/or other materials in geotechnical and civil engineering applications".

Geo-synthetics in road construction can help reduce the requirement of excavating and transporting the good soil and can help increase pavement life, which can indirectly reduce the CO_2 emissions from road construction. The greenhouse gas emission of 1 km road constructed with and without the use of geo-synthetics is 730 tCO_2-eq and 650 tCO_2-eq (Matthias Stucki et al.,2011).

IRC has published a code IRC:113. "Guidelines for the Design and Construction of Geo-synthetic Reinforced Embankments on Soft sub-soils", and MoRTH has published specifications which describe the specifications of construction aspects and design of geo-synthetic reinforced embankment.

6.3 Use of Industrial Waste

Many industrial waste materials are available in different parts of the country such as Marble dust and Slurry, quarry waste materials, Blast Furnace Slag, Steel Slag, Zinc Slag, Rice Husk

Ash, Paper Mill Sludge etc. Use of such materials has already been demonstrated in various components (embankment, base, subbase, wearing and binder layer) of construction of roads. Laboratory evaluation and proper sampling (if required) of all such material is to be done before use in actual field.

6.3.1 *Use of slag*

Copper slag, Ferro Chrome slag, Steel slag, Blast Furnace slag, Electric Arc slag, Zing slag are known as industrial waste. Steel slag, Blast Furnace slag, Electric Arc slag are by-product of steel industry. The use of industrial waste slag as aggregate in high volume applications like base, sub-bases, wearing and binder layers in both flexible and rigid pavement reduces the need for mining fresh-aggregate and the associated use of water, fuel and reduces GHG dioxide emissions. Also it will save valuable landfill space. At the same time, the performance of these materials is as good or better than natural materials, which provides added value to the project because of the reduced costs.

IRC recently has published "Guidelines for use of Iron, Steel and Copper Slag in Construction of Rural Roads (IRC:SP:121).

6.3.2 *Use of marble dust*

Solid waste and stone slurry are some of the major by-products of the marble industry. Solid wastes are the rejects from the mine sites or at the processing units and stone slurry is a semi liquid substance resulting from sawing and polishing processes. "Stone slurry generated during processing corresponds to around 20 percent of the final product from stone industry. Due to environmental and health hazards, disposal of slurry is a concern. The marble powder although non plastic contains an appreciable colloidal fraction, which significantly reduces the permeability and allows deformation without cracking which is desirable for any non- permeable structure". In road construction, it can be used as a substitute to fine aggregate due to its good binding property. Marble dust can be used as replacement of fine aggregate in both asphalt and concrete pavement for sub-base and base layer (Karasahin, M. et.al 2007 & Aliabdo, A.A et.al, 2014).By using marble dust, there can be less demand for fine aggregates, which can reduce CO_2 emissions from road construction.

Before using marble dust, laboratory evaluation through proper Marshall mix design shall be done to check the suitability of material for road construction.

6.3.3 *Use of fly ash*

Fly ash is a by-product of thermal power stations and industrial plants using pulverized coal as a fuel for the boilers. It is a fine cementitious powder, consisting primarily of silica, alumina and iron. When mixed with lime and water, the fly ash forms a compound with properties very similar to that of Portland cement. The use of fly ash as a pozzolana and fine aggregates is well established in construction sector. The uses of fly ash in road construction are discussed below:

- **Construction of Embankments–** It can save excavation and transportation of good soil to construct embankment, thus helping in reducing CO_2 emissions.

- **Stabilizing Subgrade** – Mixture of fly ash with local soil along with lime increases the strength of soil. It can also be used in stabilizing and constructing sub-base or base. In addition, the use of coal fly ash provides strong, cost effective pavement layers while reducing greenhouse gas emissions and energy consumption compared to cement.

- **Using concrete with fly ash**– Mixing concrete with fly ash (10-20 percent by weight) is a cost effective method of improving performance of rigid pavement, which also helps in reducing the quantity of cement consumed (Pranav, S., et.al, 2020).

- **Mineral filler** - Fly ash can be used to fill the voids and make bitumen mix more compact to increase the strength of the mix. This can act as replacement for many binders such as Portland cement or hydrated lime. For use in bituminous pavement, the fly ash must meet mineral filler specifications outlined in MoRTH Specifications

IRC has published IRC:SP:58 and IRC:112 that provide details of use of fly ash in embankment and in cement for concrete structure, respectively.

Further, Ministry of Environment, Forest and Climate Change(MoEFCC) vide notification bearing no. S.O. 254(E) dated 25th January, 2016 has made use of flyash mandatory for roads construction within 300 km radius of thermal power stations.

6.3.4 *Use of construction and demolition waste*

The aggregates obtained from construction and demolition waste (C&D) can be re-used in road construction for flexible/rigid pavement construction, as kerb stones, paver blocks, etc. This can reduce use of natural aggregates in road construction, which in turn can help in reducing extraction of natural aggregates and less transportation requirement, thereby reducing CO_2 emissions from use of natural aggregates in road construction. Several studies have indicated that building debris can be effectively used as road material. Several other studies have suggested potential use of C&D waste in embankment and Sub-Grade construction, Sub-Base construction, stabilized base course construction and rigid pavement construction. India Roads Congress (IRC) has "issued IRC:121 "Guidelines for use of C&D Waste in Road Sector".

It has been analyzed that the performance of blended mixture of 25% of recycled concrete aggregates with 75% of natural aggregate in the base course application has the same resilient response as the dense graded aggregates of base course made of natural aggregates. The strength and compactability of recycled CDW aggregates is similar to the conventional WBM or WMM (Rajiv Goel, et.al., 2015). Proper sampling, segregation and gradation shall be done before using C&D waste in Road Construction.

6.3.5 *Use of foundry sand*

Foundry industries are widely spread across the country. The basic operations of these industries are metal casting. Foundry industries generate waste foundry sand which is used for landfills or is disposed of near water sources creating environmental hazards. Foundry sand can be used in road construction. Studies show that waste foundry sand can be used as the fine material in road base. Engineering properties that characterize foundry sand as a Sub-Base material are plasticity, shear strength, compaction, drainage and durability. Waste foundry is non-plastic clays or dirty sands which is comparable to conventional sand. Its shear strength is superior to silts, indicating that foundry sand has also the potential for use as an embankment material as it

has more permeability than materials conventionally used for embankment construction. There is a need to promote use of foundry sand in road construction, which at present is very low. It can help address environmental concerns related to disposal of foundry waste and can also help reduce CO_2 emissions from Road Construction.

6.4 Recycling and Reuse of Material in Bituminous Layers

Many of by-products/ wastes like plastic, rubber will remain in the environment for thousands of years. These non–decaying substances if used in bituminous layer of roads can reduce environmental damages.

6.4.1 *Use of plastic waste*

There are two methods for blending of plastic waste in bituminous roads. First one is the dry process in which the aggregates are heated to 170°C in the hot mix plant and the shredded plastic waste is added. The plastic gets coated over the aggregate uniformly after which hot bitumen at 160°C is added and the road is paved using this mixture. The second process is the wet process where shredded waste plastics are directly mixed with hot bitumen at 160°C. Since the wet process requires a lot of investment and bigger plants, this process is less popular (TERI, 2017).

In order to encourage the use of plastic waste, MoRTH has decided that bituminous mix with plastic waste shall be the default mode for periodic renewal of highways falling within the 50 km Periphery of an urban area, having population of more than 5 lakh. IRC:SP:98 has framed Guidelines for the use of waste plastic in hot bituminous mixes in wearing courses. Hundreds of km of PMGSY rural roads have been constructed by use of plastic waste.

6.4.2 *Use of rubber waste*

The environmental hazards related to the disposal of waste materials of tyre industry are a big concern. The primary use of scrap tyre in road construction occurs as an additive in asphalt. This rubber is generally granulated and referred as crumb rubber modifier. Rubber, when added to asphalt, increases its durability and workability, hence improving pavement quality and safety conditions by absorbing the rubber elastic properties.

Bitumen modified with crumb rubber (waste tyre) gives better resistance to fatigue and stripping improves the elastic modulus and increases the load carrying capacity of the pavement. It delays oxidation of mix, enhancing the pavement life. It addresses the environmental concerns related to the discarded tyres of automobiles. Using modified bitumen mix can increase the life of pavements and can reduce the pavement thickness, which in turn reduces the maintenance requirements and demand of natural aggregates etc. (Newman, et al.,2012).

Modified crumb rubber is being used in various countries like the USA, South American Nations, and Malaysia. In India, the concept of usage of waste tyre/crumb rubber for the roads took off two decades back Proper quality control meanues need to be carried out while using modified bitumen.

IRC:SP:53, gives specifications regarding the use of crumb rubber bitumen. There is also an IS Code (IS 15462: 2019) for the Specification of Polymer and Rubber Modified Bitumen.

6.4.3 *Use waste materials as alternative fillers*

Mineral filler is the finest aggregate in the bituminous mix which mostly passes through a particular sieve (0.075 mm in India) Materials such as stone dust, hydrated lime and ordinary Portland cement (OPC) are traditionally used as fillers.

Mixing locally available waste materials as fillers in bituminous pavement will lead to reduced consumption of natural resources/ naturally mined materials, reduced haulage distance therefore, minimizing the carbon footprint of pavements. Some of the waste materials commonly being used worldwide as alternative to filler of bituminous pavement are Rice Husk Ash; Sugarcane Bagasse Ash; Brick Dust; Concrete Dust; Coal Fly Ash; Cement Kiln Dust; Marble Dust; Granite Dust; Limestone Dust; Ceramic Waste; Copper Industry Waste; Blast Furnace Slag; Basic Oxygen Furnace Slag; Ladle Furnace Slag; Electric Arc Furnace Dust; Phosphogypsum; Red Mud; Sewage Sludge Ash; Municipal Solid Waste Incineration Ash; Glass Powder; Coal Mine Waste etc. (Choudhary, J., et.al., 2020).

Before using waste material as filler to bituminous pavement, Specific gravities of waste fillers is to be determined as per IS:2720(Methods of Tests for Soils, Bureau of Indian Standards).

6.4.4 *Use of RAP material*

The conventional hot mix method of providing bituminous courses in flexible pavements requires significant amount of fuel and materials. However, non-availability of good quality aggregates in some areas of the country and transportation of aggregates from longer distances is an issue of concern for highway professionals. Further, thicknesses of existing pavements are increasing with time due to rehabilitation and maintenance. Such a situation is leading to serious drainage problems especially in the urban areas. Milling of the existing pavements and recycling of these materials after suitable modification will address the problems of drainage and conservation of materials to certain extent. Therefore, the use of Reclaimed Asphalt Pavement (RAP) material in road construction is the need of the day. Recycling of existing bituminous pavement to produce new rehabilitated pavement led to considerable savings of material, expenditure, and energy.

Although the majority of old asphalt pavements are recycled at central processing plants, asphalt pavements may be pulverized in place and incorporated into granular or stabilized base courses using a self-propelled pulverizing machine.

IRC: 120 gives Specifications for Recycling of Bituminous Pavement Materials for use as RAP. Two different classifications of bituminous pavement recycling have been reported in literature such as Hot Recycling and Cold Recycling.

- **Hot Mix Recycling:** It involves combining RAP material with virgin aggregates, new bitumen binder, and/or recycling agents in a central hot mix plant to produce a recycled bituminous mix.

- **Cold Recycling:** In this process RAP material is used as an aggregate in cold bituminous mixture. In cold recycling, the old existing pavement is removed, broken into aggregate sized chunks and then combined with emulsified bitumen or foamed bitumen. Such mix is generally used as a stabilized base course under reconstruction of flexible pavements.

When the HMA mixture contains 30% of RAP by weight, it approximately saves 16% of energy and 20% of CO_2 per tonne, as compared to HMA mixture produced using the natural aggregates (Lee et al.,2011).

Besides huge savings in cost and earning carbon credits, less virgin aggregate shall be used from stone quarries by using this technology.

6.5 Low Energy Mixes Concept in Bituminous Pavement

As per GHG emission data base production of one tonne of hot mix emits about 5.25 kg of carbon. Studies reveal that production of aggregate includes quarrying, hauling, crushing and screening, the GHG emission range is 2.5 to10 kg CO_2 /t and for asphalt it is 221kg CO_2 /t (Thives, L.P., 2017). New construction, major rehabilitation and thin surfacing using hot mix technology have the highest energy use and range from 6.3- 12.6 MJ/m^2 per year. Hence, it is required to go for low energy mixes technologies.

6.5.1 *Cold mix*

Cold mix technology is alternative to hot mix technology, where aggregate and bitumen emulsion is mixed and laid at ambient temperature without heating. Cold mix technology using cationic emulsions is also promising, particularly in the areas of long spells of rainy season and cold climates. This is an environment friendly technology and is not equipment intensive. For rural roads, it would prove not only cost-effective but also enable achievement of larger lengths due to availability of longer working season particularly in north-east region and hilly states.

Using cold mix technology saves around 20-25% of energy compared to hot mix and inturn reduces emissions (Swaroopa, S.,et.al., 2015).

MoRTH Specifivations (Road and Bridge Works, 5th Revision) and IRC Specifications (IRC:SP:100) recommended use of cold liquid bitumen like bitumen emulsion as binder for tack coat in bituminous road construction and use of emulsion based technologies for road construction and maintenance.

Slurry seal and micro-surfacing is also considered cold mixes although used as surface treatment. The slurry seal consists of a mixture of mineral aggregate (mostly fine aggregate), slow setting cationic bitumen emulsion, water and additives (if needed) proportioned, mixed and uniformly spread over a prepared surface. Micro-surfacing, however, typically uses a polymer-modified asphalt emulsion and larger particle of aggregate.

Specifications of Design and Methodology of Micro-Surfacing Technology including different types of Micro-Surfacing and its constituent materials are provided in IRC:SP:81.

6.5.2 *Warm mix*

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow producers of Hot Mix Asphalt (HMA) pavement material to lower temperatures at which the material is mixed and placed on the road. It is a proven technology that can:

- Reduce Paving Costs.

- Extend the Paving Season.
- Improve Asphalt Compaction.
- Allow Asphalt Mix to be hauled for longer distances.
- Improve working conditions by reducing exposure to fuel emissions, fumes, and odors.

Studies have reported that for every 10^0C increase in mix production temperature, the amount of GHG emissions becomes two fold. Warm Mix Asphalt (WMA) represents the technologies that allow the reducing of bituminous mixing and compaction temperatures by reducing its bitumen viscosity. WMA production methods use temperatures 20^0 to 50^0C lower than traditional hot-mix asphalt. Because less energy is needed to heat the asphalt mix, less fuel is needed to produce WMA. Fuel consumption during WMA manufacturing is typically reduced by 20%.

Additionally, WMA saves time in production as well as in surfacing roads. Lower temperatures also permit more asphalt mix to be hauled for longer distances.

As per the Central Road Research Institute (CRRI) report, use of Warm Mix Asphalt in place of Hot Mix Asphalt can reduce 32 gm CO_2 eq. per m^2. On an average 20 to 40 % reduction in emissions may be observed by use of WMA in place of HMA. WMA technology has proven results in all terrain and climatic conditions. Its use in India has consistently increased over the years. IRC:SP:101 provides detailed Guidelines on WMA in Road Construction.

PART - III

GHG ESTIMATION METHODOLOGY FOR VEHICULAR EMISSION DURING OPERATIONS STAGE OF ROADS

1. Factors of GHG Emission Estimation during Operations Stage

There are several factors affecting GHG emission from vehicles during operations stage of a road. They are as given below.

a) Fleet Composition (by Fuel Type and Vintage Year)
b) Mode Wise Fuel Efficiency
c) Traffic Volume
d) Trip length or Project Road Length
e) Road Configuration
f) Pavement Roughness
g) Existing or Proposed Tree Cover
h) Volume by Capacity (V/C) Ratio

2. GHG Estimation Methodology during Operation Period

Main activities or components to be considered for computing GHG emission during operation are as follows:

- Direct and embodied emission due to combustion of fossil fuels by vehicles plying on the road.
- Carbon sequestration due to existing and proposed tree plantation along the project road.
- Embodied GHG emission of vehicles is not considered for roads as it will lead to multiple counting

Inputs

Carbon emission in this stage accounts to vehicular traffic plying in the road stretch over a period of time. Input factors to be used are as follows:

- Hourly 24 hours mode wise traffic count in vehicles
- Fuel based Segregation of traffic i.e. Diesel/ petrol/ CNG. This data can be obtained from Fuel station Survey
- Vintage year based segregation of traffic- 1996-2000, 2000-2005, 2005 - 2010, 2010 - 2015 and so on based on the availability of vintage year and Bharat stage wise emission factors. Vintage year wise segregation can be done based on data collected from Fuel station Survey.
- CO_2 emission factor based on fuel and vintage year (for each type of vehicle) (ARAI, 2007)

Methodology

Option-1

The methodology to be adopted for calculation is as follows **(Fig. 3.1)**

- Mode wise segregation of hourly data viz. Car, 2-Wheeler,3-Wheeler for Passenger, Light Commercial Vehicles, Heavy Commercial Vehicles and Bus .
- Estimation of the share of different fuel types (viz. petrol, Diesel and CNG) out of each mode wise hourly number of vehicles
- Number of vehicles of each fuel type of every mode shall then be distributed vintage year wise
- The above distributed values are then multiplied with the corresponding Carbon Dioxide emission factor as can be sourced from CPCB and ARAI (last updated in 2008). Thus, emission from each mode is calculated in grams/km.
- Total of emission from all modes shall then be summed up to provide emission in grams per kilometer carbon dioxide for one homogenous/ project section (in terms of traffic). The value in grams/km is then multiplied with the distance of the homogenous section.
- Value of each homogenous section is then added to get the total carbon dioxide emission and multiplied with 365 days to get annual emission.
- One project road may have one or more homogenous sections in terms of traffic.

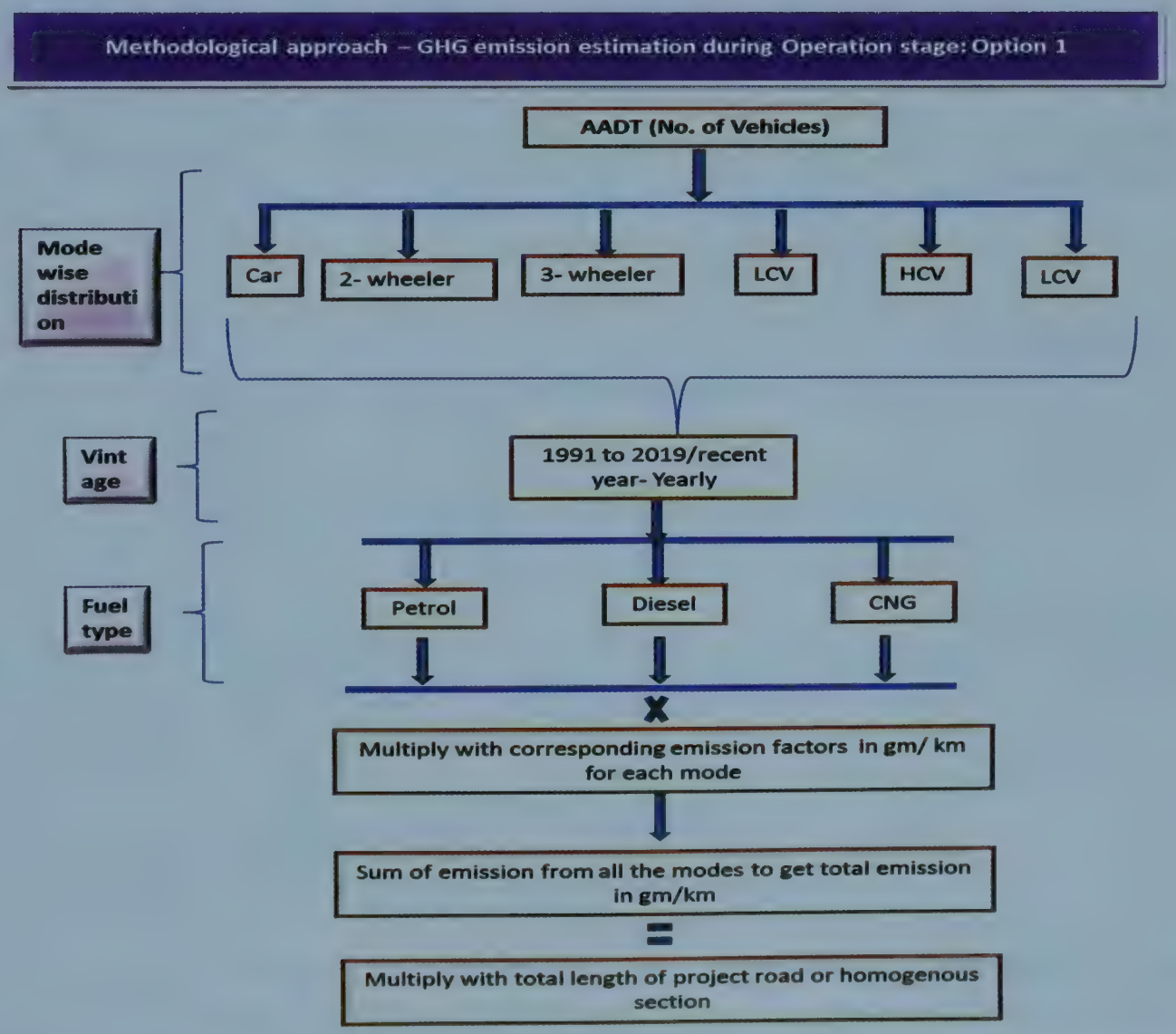
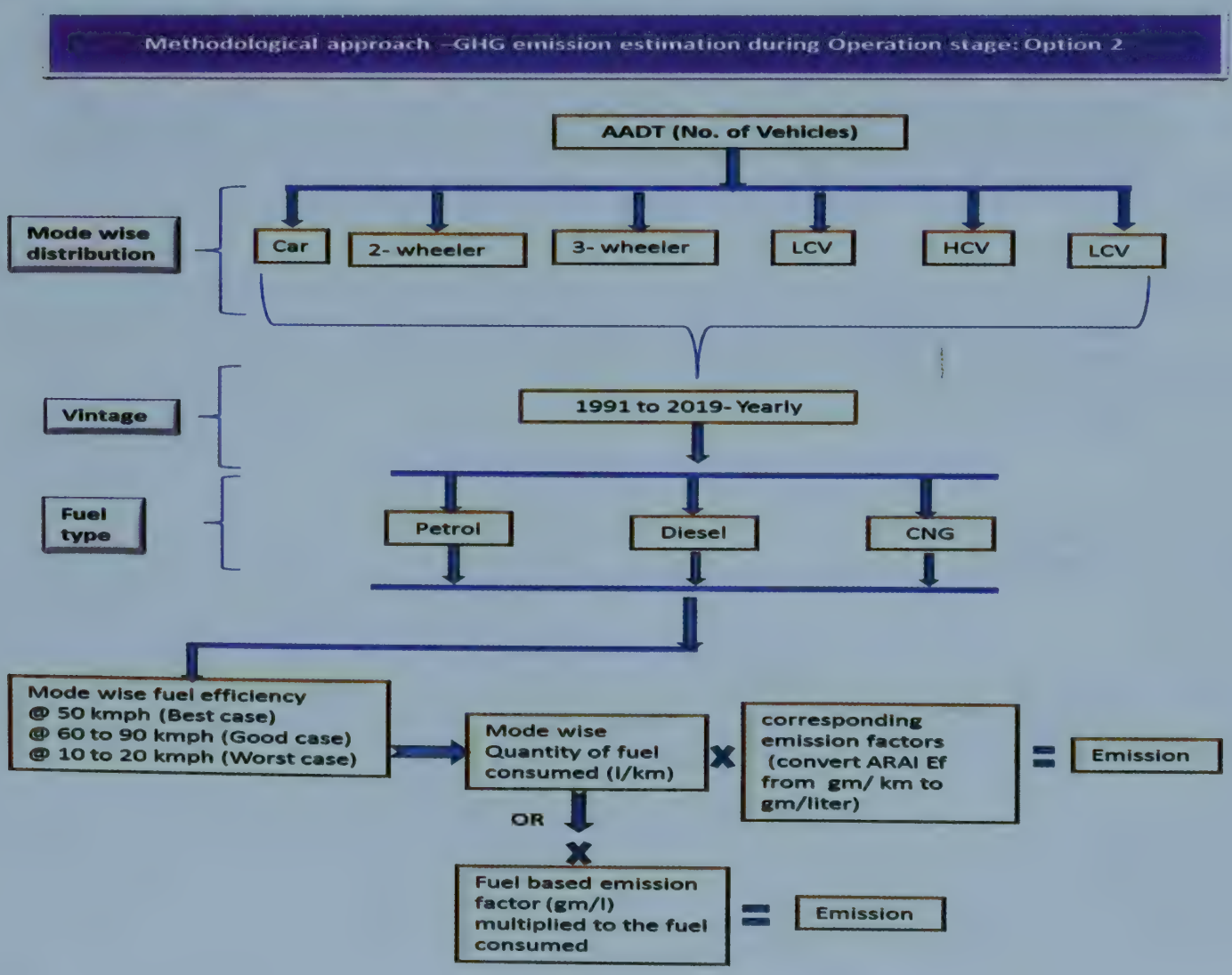

Methodological approach – GHG emission estimation during Operation stage: Option 1
AADT (No. of Vehicles)
Mode wise distribution
Car
2- wheeler
3- wheeler
LCV
HCV
LCV
Vint age
1991 to 2019/recent year- Yearly
Fuel type
Petrol
Diesel
CNG
Multiply with corresponding emission factors in gm/ km for each mode
Sum of emission from all the modes to get total emission in gm/km
Multiply with total length of project road or homogenous section

Fig.3.1 Methodological Approach–GHG Emission Estimation during Operation Stage: Option-1

Option-2 (considering speed)

The methodology to be adopted for calculation is as follows **(Fig. 3.2)**

- Mode wise segregation of hourly data viz. Car, 2-Wheeler,3-Wheeler for Passenger, Light Commerical Vehicles, Heavy Commerical Vehicles and Bus .
- Number of vehicles of each fuel type of every mode shall then be distributed vintage year wise
- Estimation of the share of different fuel types (viz. petrol, Diesel and CNG) out of each mode wise hourly number of vehicles
- Calculate fuel consumption for the entire length of Project Road or Homogenous Section based on vehicle mileage and speed(worst case @ 10-20 kmph; good case @ 60 to 90 kmph and best case @ 50 kmph)
- Multiply the fuel quantity with their corresponding emission factors to get the total emission.
- Further, multiply with 365 days to get annual emission
- In case the user has data on working hours of vehicle, multiply it with fuel consumed per hour and then calculate its emission as given above.



PS: The speed considered for different mode of vehicles would be the base year's and projected years's journey speed depending on roughness of surface and v/c ratio.

Fig. 3.2 Methodological Approach – GHG Emission Estimation during Operation Stage: Option-2

Relation between Speed and Emission

Speed of vehicles is a major factor contributing to fuel efficiency and carbon emissions. As referred from various studies (ADB, 2010 and Thomas, et.al., 2009) a speed between 40 to 60 km/hr serves best in reducing the emissions and shows an increasing trend < 40 and > 60km/hr. The increase is accelerated when speed reduces from 50 kmph than when speed rises above 50kmph **(Table 3.1 & Fig.3.3).** The percentage changes in emission are with reference to the value of emission at 50 kmph and CO_2 emitted would differ for different vehicles based on modes, fuel type and vintage of a vehicle.

Roughness and V/C ratio that may affect fuel efficiency and carbon emission can be represented through speed.

Table 3.1 Impact of Speed on Vehicle Emission

Sl. no	Speed (kmph)	Emission (% change)
1	0-20	65 to 35%
2	20-25	35 to 20 %
3	25-30	20 to 12 %
4	30- 35	12 to 5 %
5	35-40	5 to 3%
6	40-60	0 to 3%
7	60-65	3 to5%
8	65- 70	5 to 10%
9	70-75	10 to 14%
10	75-80	14 to 22%
11	80-85	22 to 24.5%
12	85-90	24 to 33%
13	90-95	33 to 36%

(Source: ADB,2010)

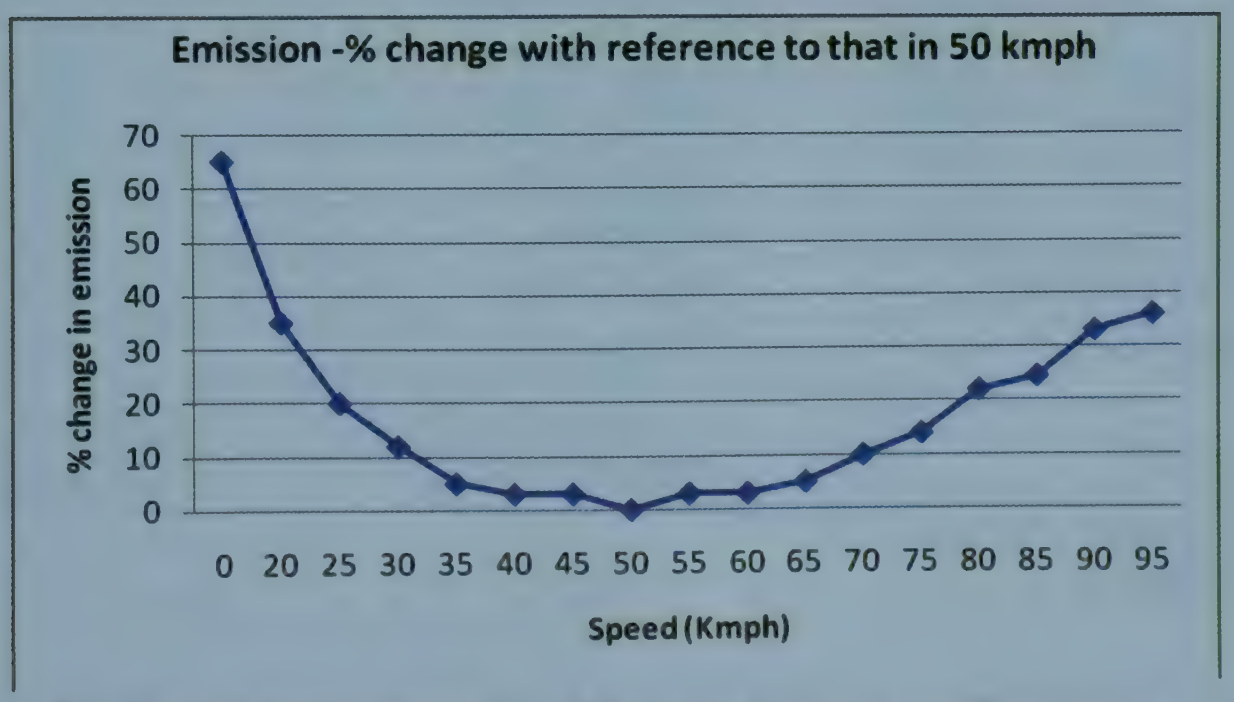


Fig. 3.3 Relation between Vehicular Speed and Emissions

3. CO_2 Emission Factors of Fuel (by Fuel Type, Mode of Vehicle and Age)

Emission factors specific to India are available from ARAI & CPCB. Emission factors for CO_2 as given in Air Quality Monitoring Project- Indian Clean Air Program (ICAP), 2007, Draft Report on 'Emission Factor Development for Indian Vehicles' CPCB & ARAI, Pune are given in **Table 3.2.** For details, one may refer the above mentioned document or as updated from time to time.

Table 3.2 CO_2 Emission Factors for Fuel by Type, Mode and Age as Per ARAI

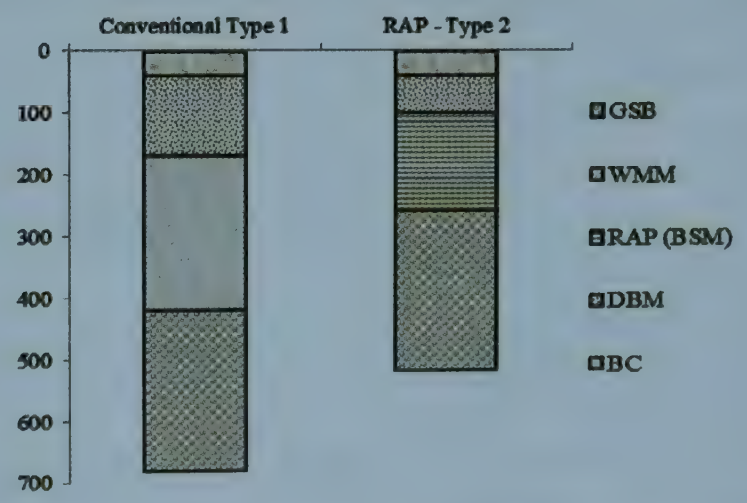
Type	Year	CO_2 (gm/km)
2-Wheeler (2 Stroke) (Scooters) (>80CC)	1991-1995	24.75
	1996-2000	25.05
	2001-2005	25.92
	>2006	38.84
2-Wheeler(4 Stroke) (Motor Cycles) (<100CC)	1991-1995	22.42
	1996-2000	23.25
	2001-2005	24.97
	>2006	45.60
3W (Compressed Natural Gas) 4Stroke	≥2001 (OEM Vehicles)	77.70
	≥2001 (Retrofitted Vehicles)	57.71
Passenger Cars (Petrol) (<1000CC)	1991-1995	95.96
	1996-2000	98.61
	2001-2005	126.37
	2006-2010	126.80
Passenger Cars (Diesel) (<1600CC)	1996-2000	129.09
	2001-2005(BS-I)	156.76
	2001-2005(BS-II)	154.76
	>2005	148.76
LCV (<3000CC)	1991-1995	327.29
	1996-2000	333.31
	>2001	401.25
Bus/HCVs (Diesel) (>6000CC)	1991-1995	817.52
	1996-2000	920.77
	2001-2005	668.00
	2006-2010	602.01
Bus (CNG) (>6000CC)	≥ 2001	806.50
PS: This is representative of the detailed data that can be accessed from ARAI		

PART - IV

CASE STUDY

A case study has been given in this Section to explain the methodologies given in this document for ease of reference to users. Data used here has been extrapolated for 1 km from representative projects. However it is not advisable to adopt the results as a rule of thumb because activities and quantities will not be limited to what have been calculated here and may differ based on site/project specific condition. Further refining of data and assessment can be done once this guideline is adopted holistically in detailed Design/EIA studies. This study considers two options and the details are as given in **Table 4.1.**

Table 4.1 Project Details of Option-1 & Option-2

S.No	Project Details	Option -1	Option-2
1	Pavement Technology	Recycled Asphalt Pavement	Conventional Flexible Pavement (Hot Mix)
2	Existing lane configuration	2-lane with average intermediate width of 5 m	Greenfield/ Realignment
3	Proposed lane configuration	2-lane (3.5mx2) + paved shoulder (2x1.5m)+ earthen shoulder (2x1m)	2-lane (3.5mx2) + paved shoulder (2x1.5m)+ earthen shoulder (2x1m)
4	Drain / embankment/ any other structure	Not considered	Not considered
5	Length	1km	1km
6	Traffic Volume (AADT in vehicles)	4204 in base year and 8804 in 15th year	
7	Pavement Design Specification	CBR 6% & Design Traffic of 60 MSA. Design Period- 15 years	
8	Pavement Composition		
9	Number of trees to be felled	261	749
10	Number of trees to be planted as part of CA	522	1498
11	Soil area to be paved	7000 sqm	12000 sqm

For RAP, it is proposed for full depth removal of the bituminous surfacing by multi-stage cold milling and mixing the reclaimed material with beneficiating additive (such as virgin aggregate, bitumen emulsion, etc.). Cold recycling of the bituminous surfacing and reclaimed in stabilized base course which will substitute the conventional granular base layer generally provided in the form of WMM layer.

Comparative assessment shows that Option -1 will use 35% less fresh material (aggregates, bitumen, soil) and emit 32% less GHG compared to option -2 during construction and maintenance of pavement **(Tables 4.2 and 4.3).** Emission has been adjusted with loss and gain of carbon sink of soil and trees. In terms of GHG, option -1 is preferred. However, finalization of option shall depend on other parameters as well, like cost, technical feasibility, land availability etc.

Table 4.2 GHG Emission (tCO_2e) from Different Activities during Construction & Maintenance of Pavement over Design Period

S.No	Activities	Construction Stage		Maintenance Stage		Detailed calculation ref.
		Option -1	Option-2	Option-1	Option-2	
1	Construction materials/ fuel (tCO_2e)	191302	245725	36430	36430	Table 1 of Appendix -1
2	Onsite activities (tCO_2e)	901.13	1051.32	120.15	120.15	Table 1 of Appendix -1
3	Transportation of construction materials (tCO_2e)	545317	861306	1644	1644	Table 2 of Appendix -1
4	Loss of carbon sink due to paving of soil (tCO_2e) (added to total emission)	22.86	39.19	0	0	Appendix - 2
5	Loss of carbon sink due to loss of vegetation (tCO_2e) (added to total emission)	19.02	384.95	0	0	Appendix -3
6	Gain of carbon sink due to CA (tCO_2) (deducted from total emission)	16.82	48.26	160.58	460.81	Table 1 to 4 of Appendix 4
7	Gain of carbon sink due to soil in CA area (tCO_2e) (deducted from total emission)	Negligible	Negligible	122.75	352.27	Table 5 of Appendix 4
	Total	**737545**	**1108458**	**37911**	**37381**	

Table 4.3 Summarized Results of GHG Emission in tCO_2e

Stages	Option -1	Option-2	% reduction in emission for Option-1
Construction	737558	1108495	33.46
Maintenance	38024	37705	-0.84
Total	**775581**	**1146200**	**32.33**

Due to data constraints, the vehicular emission part has been calculated only for base and 15th year considering the Roughness Index and volume –capacity ratio same for both the options. However, in case a 'no project' scenario is considered, journey speed is likely to decrease over years due to increase in roughness and volume capacity saturation. This may be referred only for understanding the procedure. As per this study, annual vehicular emission is likely to increase by 30% from 853 tCO_2e in 1st year to 1226 tCO_2e per km in 15th year.

PART - V

CONCLUSION

This guideline will provide a standardized common basis for GHG estimation and reduction for road activities that will help in decision making while choosing a less GHG intensive project option. This will also help in preparation of a national report card in terms of roads. It may be noted that application of any of the technologies mentioned in Part-II can prove GHG efficient based on site specific conditions only and hence it is recommended to prioritise on the GHG efficient technologies and materials based on site conditions.

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TABLE-1 GHG Emission Calculation for Construction Materials, Fuels and Onsite Activities during Construction and Manitenance

Materials (unit)	Option -1: RAP for upgradation of Existing 2-Lane Road of 1 km					Option-2: Conventional Flexible Pavement for Realignment of 2 Lane Road of 1 km			
	Construction	Emission factor (tCO_2e/ ton)	Maintenance (once in 5 years for 15 years)	Emission during construction (tCO_2)	Emission during maintenance (tCO_2)	Construction	Maintenance (once in 5 years for 15 years)	Emission during construction (tCO_2)	Emission during maintenance (tCO_2)
Aggregate (t)	498986	0.0052	0	2595	0	896330	0	4661	0
Bitumen VG-40 (t)	2575	0.49	136	1262	67	4402	136	2157	67
Bitumen emulsion(t)	2714	0.49	0	1330	0	0	0	0	0
Soil (t)	504900	0.024	0	12118	0	659700	0	15833	0
Recycled Asphalt (t)	141247	0	0	0	0	0	0	0	0
Diesel (L) used in equipment/ machines	65000	2.6769 tCO_2e/L	13584	173998	36364	83333	13584	223075	36364
Electricity (MWh) @ 0.212kWh/ capita/day	0.954	0.82 tCO_2 / MWh	0.1272	0.78228	0.104304	1.113	0.1272	0.91266	0.104304
LPG @3.724 l/ capita/month	558.6	1.6118 tCO_2e/L	74.48	900.35148	120.046864	651.7	74.48	1050.41006	120.046864
No. of labours/ day	50		20			50	20		
Construction period (month)	3		1			3.5	1		
Total Fresh Material	1009175		136			1560431	136		
Total Emission				**192203**	**36550**			**246777**	**36550**

Please note:

a) Calculation may not be limited to the above mentioned items or activities depending on Specific Site/ Project Conditions

b) Emission factor of bitumen emulsion has been taken same as that of bitumen due to unavailability of data in Open Access sources

TABLE-2 GHG Emission Calculation for Tranportation of Materials during Construction and Maintenance

Materials (unit)	Distance from Source (km)	Transportation Mode	Mileage km/L	Option-1: Fuel Consumption in Transportation (L)		Option -1: Emission Factor tCO_2e (@ 2.6769 tCO_2e/		Option-2: Fuel Consumption in Transportation (L)		Option -2: Emission Factor tCO_2e (@ 2.6769 tCO_2e/L)	
				Construction	Maintenance	Construction	Maintenance	Construction	Maintenance	Construction	Maintenance
Aggregate (t)	15	4x2 axle -16 t	6.25	149696	0	400721	0	268899	0	719815.4	0
Bitumen VG-40 (t)	250	6x4-axle 25t	4.42	18185	614	48680	1644	31086	614	83213.98	1643.630258
Bitumen emulsion (t)	250	6x4-axle 25t	4.42	19169	0	51315	0	0	0	0	0
Soil (t)	1.65	2 axle -16 t	6.25	16662	0	44602	0	21770	0	58276.38	0
				203712	614	545317	1644	321755	614	861306	1644

PS: Calculation may not be limited to the above mentioned items or activities depending on Specific Site/ Project Conditions

APPENDIX-2

Loss of Carbon Sink due to Paving of Soil

	Option -1: RAP for Upgradation of Existing 2-Lane Road of 1 km	Option -2: Conventional Flexible Pavement for Realignment of 2 Lane Road of 1 km
Length (m)	1000	1000
Project Lane Configuration	2 lane to 2 lane with Paved shoulder and Earthen Shoulder	New 2 lane with Paved and Earthen Shoulder
Pre Project Paved area sqm	5000	0
Post Project Paved Area	12000	12000
Soil Area converted to Road (sqm)	7000	12000
Agricultural Soil Area converted to Road (Ha)	0.7	1.2
% Organic Carbon	0.3	0.3
Bulk Density (mega gram/ cum)	1.2	1.2
% stones	0.07	0.07
SOC Stock (kg/ha)	6770.4	6770.4
SOC Stock (t)- Removal	4.73928	8.12448
CO_2 sequestered (t)- Removal	17.38	29.79
CO_2e sequestered (t)- Removal	22.86	39.19

TABLE-1 Loss of Carbon Sink due to Tree Felling in Option -1

S. no	Species (Local Name of Trees)	Approx Height (feet)	Diameter (inch)	If D <11, W=0.25*D^2*H (In pounds)	If D >=11, W=0.15*D^2*H (In Pounds)	BGTB (Pounds)	Total weight (AGTB +BGTB) in Pounds	Dry weight of tree (Pounds)	Weight of Carbon in Tree (Pound)	Weight of CO_2 in tree (t)
1	Babla	10.00	3.0	22.56		6.09	28.65	20.76	10.38	0.02
2	Babla	12.00	4.0	48.12		12.99	61.12	44.30	22.15	0.04
3	Babla	10.00	3.8	35.25		9.52	44.76	32.45	16.23	0.03
4	Babla	12.00	9.4	264.34		71.37	335.72	243.39	121.70	0.20
5	Babla	12.00	3.0	27.07		7.31	34.38	24.92	12.46	0.02
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
252	Sirual	15.00	3.4	42.82		11.56	54.39	39.42	19.71	0.03
253	Sirual	10.00	2.8	18.95		5.12	24.07	17.45	8.73	0.01
254	Arjun	12.00	8.5	217.30		58.67	275.97	200.08	100.04	0.17
255	Arjun	15.00	8.1	248.19		67.01	315.20	228.52	114.26	0.19
256	Arjun	15.00	11.9		318.094041	85.89	403.98	292.88	146.44	0.24
257	Sirish	15.00	3.0	33.84		9.14	42.97	31.15	15.58	0.03
258	Sirish	15.00	2.8	28.43		7.68	36.11	26.18	13.09	0.02
259	Sirish	15.00	2.8	28.43		7.68	36.11	26.18	13.09	0.02
260	Sirish	15.00	3.5	46.05		12.43	58.49	42.40	21.20	0.03
261	Babla	12.00	3.3	31.77		8.58	40.35	29.25	14.63	0.02
	Total			17723	1305	4785	22508	16318	8159	14.45
	Total tCO_2e									**19.02**

Please note: This Table have been represented partially to show the calculation procedure only and avoid adding unnecessary volume to the document

TABLE- 2 Loss of Carbon Sink in Option-2

S. no	Species	Height of Tree	Diameter (inch)	If D <11, W=0.25*D^2*H (In Pounds)	If D >=11, W=0.15*D^2*H (In Pounds)	BGTB	Total weight (AGTB +BGTB) in Pounds	Dry Weight of tree (Pounds)	Weight of Carbon in Tree (Pound)	Weight of CO_2 in Tree (t)
1	Neem	15	7	178		48	226	164	82	0.13
2	Neem	15	11		249	67	316	229	114	0.19
3	Simul	18	8	254		69	322	234	117	0.19
4	Ber	15	11		255	69	323	234	117	0.19
5	Simul	15	7	204		55	260	188	94	0.16
6	Gumhar	15	12		298	81	379	275	137	0.23
7	Gumhar	20	8	282		76	358	260	130	0.21
8	Ber	15	12		298	81	379	275	137	0.23
9	Ber	15	21		1019	275	1294	938	469	0.77
10	Gumhar	10	8	141		38	179	130	65	0.11
-	-	-	-	-	-	-	-	-	--	-
-	-	-	-	-	-	-	-	-	--	-
-	-	-	-	-	-	-	-	-	--	-
745	Peepal	60	46		19301	5211	24512	17771	8886	14.66
746	Gamhar	30	11		534	144	678	491	246	0.41
747	Palas	25	16		993	268	1261	914	457	0.75
748	Savda	20	16		734	198	933	676	338	0.56
749	Savda	9	6	71		19	91	66	33	0.05
Total				116525	268654	103998	489177	354654	177327	292.56
									Total tCO_2e	**384.95**

Please note: This Table have been represented partially to show the calculation procedure only and avoid adding unnecessary volume to the document

Table -1 Compensatory Afforestation with Neem Tree: CO_2 Sequestrationin 1st Year for Option-1

D(m)	H(m)	V (cum)	Wood Density (t d.m. cubic m)	CF tC/tdm	BEF	CAB (t)	AGTB (t)	BGTB (t) @ 0.27 of AGTB	C in BGTB (t) @ 50% of dry biomass	C in AGTB+BGTB	Wheight of CO_2 sequestered by tree (t)
0.04	1.5	0.009951	0.69	0.5	1.58	0.005424	0.010317	0.002786	0.001253529	0.006678	0.02
Total neem trees planted under CA is 261x2, hence total CO_2 sequestration possible in 1st year of plantation is (assuming average D as 0.04m and H as 1.5 m											12.78
										tCO_2e	16.82

Table-2 Compensatory Afforestationwith Neem Tree: CO_2 Sequestration in 1st Year for Option-2

D m)	H(m)	V (cum)	Wood Density (t d.m. cubic m)	CF tC/ tdm	BEF	CAB=VXDXBEFXCF (t)	AGTB (t)	BGTB (t) @ 0.27 of AGTB	C in BGTB (t) @ 50% of dry biomass	C in AGTB+BGTB	Wheight of CO_2 sequestered by tree (t)
0.04	1.5	0.009951	0.69	0.5	1.58	0.005424	0.010317	0.002786	0.001253529	0.006678	0.02
Total neem trees planted under CA is 749x2, hence total CO_2 sequestration possible in 1st year of plantation is (assuming average D as 0.04m and H as 1.5 m)											36.67
										tCO_2e	48.26

Table-3 Compensatory Afforestation With Neem Tree: CO_2 Sequestration in 15Th Year for Option-1

D(m)	H(m)	V (cum)	Wood Density (t d.m. cubic m)	CF tC/ tdm	BEF	CAB=VXDXBEFXCF (t)	AGTB (t)	BGTB (t) @ 0.27 of AGTB	C in BGTB (t) @ 50% of dry biomass	C in AGTB+BGTB	Wheight of CO_2 sequestered by tree (t)
0.13	7.77	0.056192	0.69	0.5	1.58	0.03063	0.010317	0.002786	0.001253529	0.031884	0.12
Total neem trees planted under CA is 261x2, hence total CO_2 sequestration possible in 1st year of plantation is (assuming average D as 0.13m and H as 7.77 m)											61.02
										tCO_2e	80.29

Table-4 Compensatory Afforestation With Neem Tree: CO_2 Sequestration in 15Th Year for Option-2

D(m)	H(m)	V (cum)	Wood Density (t d.m. cubic m)	CF tC/ tdm	BEF	CAB = VXDXBEFXCF (t)	AGTB (t)	BGTB (t) @ 0.27 of AGTB	C in BGTB (t) @ 50% of dry biomass	C in AGTB+ BGTB	Wheight of Co_2 sequestered by tree (t)
0.13	7.77	0.056192	0.69	0.5	1.58	0.03063	0.010317	0.002786	0.001253529	0.031884	0.12
Total neem trees planted under CA is 749x2, hence total CO_2 sequestration possible in 1st year of plantation is (assuming average D as 0.13m and H as 7.77 m)											175.11
										tCO_2e	230.41

Table-5 Sequestration By Soil in Compensatory Afforestation Land by 15Th Year (Previously Non –Vegetated/ Degraded)

	Option -1	Option -2
Area (Ha) @6 x6 m spacing	1.8792	5.3928
SOC stock (kg/ha)	6770.4	6770.4
SOC stock (t)- Addition	12.72	36.51
CO_2 sequestered (t)- Additional	46.65	133.86
CO_2e sequestered (t)- Additional	**61.38**	**176.13**

CO_2 EMISSION FROM VEHICLES DURING OPERATION PERIOD

	Traffic Volume			Vintage Year Wise Distribution					Vintage & Fuel Wise Distribution					
Mode	AADT (vehicles)	BS-II (2001-2005)	BS-III (>2006)	BS-II (2001-2005)	BS-III (>2006)	BS-II (2001-2005)-Petrol	BS-II (2001-2005)-Diesel	BS-III (>2006)-Petrol	BS-III (>2006) Diesel	BS-II (2001-2005)-Petrol	BS-II (2001-2005)-Diesel	BS-III (>2006)-Petrol	BS-III (>2006) Diesel	
	1st yr	15th yr	1st yr	15th yr	1st Year	15th Year								
2-Wheeler	2924	6079	1608	1316	608	5471	1608	0	1316	0	608	0	5471	0
3-Wheeler	21	49	17	4	5	44	0	17	0	4	0	5	0	44
Car	698	1593	314	384	159	1434	214	101	261	123	108	459	975	459
LCV	188	318	122	66	6	312	0	122	0	122	0	6	0	312
Bus	47	67	31	16	1	66	0	31	0	31	0	1	0	66
HCV	326	698	212	114	14	684	0	212	0	212	0	14	0	684

Mode	Emission factor tCO_2/l		Fuel/ mileage @ 50 kmph Journey Speed Depending on RI and V/C ratio				Total Emission tCO_2							Total Emission tCO_2		
	Petrol	Diesel	Petrol (L/m)	Diesel (L/m)	Petrol (L/km)	Diesel (L/km)	BS-II (2001-2005)-Petrol	BS-II (2001-2005)-Diesel	BS-III (>2006)-Petrol	BS-III (>2006) Diesel	BS-II (2001-2005)-Petrol	BS-II (2001-2005)-Diesel	BS-III (>2006) - Petrol	BS-III (>2006) Diesel	1st year	15th year
			1st yr		15th yr		1st Year				15th Year					
2-Wheeler	2.27	2.68	0.02		0.02		81.20	0.00	66.44	0.00	27.62	0.00	249	0	147.64	276.24
3-Wheeler	2.27	2.68		0.06		0.05	0.00	2.50	0.00	0.06	0.00	0.66	0	6	2.55	6.56
Car	2.27	2.68	0.08	0.07	0.07	0.05	40.44	17.94	49.43	0.02	16.41	61.41	148	61	107.83	286.89
LCV	2.27	2.68		0.20		0.13	0.00	65.42	0.00	65.42	0.00	2.13	0	104	130.85	106.41
Bus	2.27	2.68		0.20		0.13	0.00	16.36	0.00	16.36	0.00	0.45	0	22	32.71	22.42
HCV	2.27	2.68		0.20		0.13	0.00	113.45	0.00	113.45	0.00	4.67	0	229	226.89	233.56
															648.47	932.08
tCO_2e															853.25	1226.42

Please note:

1. Considered till BS-III as Traffic Data and projections used are old just for calculation purpose.
2. Updated emission factors based on Bharat Stages shall be used.
3. As data has been rounded up to 2 decimal places at each stage there might be slight variation in sum.
4. Vintage, mileage & Fuel wise distribution can be obtained from fuel station & Origin Destination survey.
5. If emission factor of vehicles are not available as per BS/ vintage year, one shall consider latest emission factors of fuel and multiply with average mileage recorded for particular vehicle.
6. Due to data constraint speed has been taken as 50kmph for all modes.
7. Since, both the options are presumed to maintain adequate Roughness Index through regular maintenance, journey speed has been assumed to be same over the design period. However, for an option of no project scenario, RI will tend to increase and journey speed will tend to decrease over the years and shall be taken into consideration. It must also be accounted for that with saturation of V/C ratio over the years, journey speed also tends to decrease.

(The Official amendments to this document would be published by the IRC in its periodical, 'Indian Highways' which shall be considered as effective and as part of the Code/Guidelines/Manual, etc. from the date specified therein)

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